Factors determining agricultural damage from foraging ungulates

– an experimental study using exclosures in oat- and grass fields

Faktorer som påverkar jordbruksskador från klövviltsbete – en experimentell studie med uthägnader i havre- och vallfält

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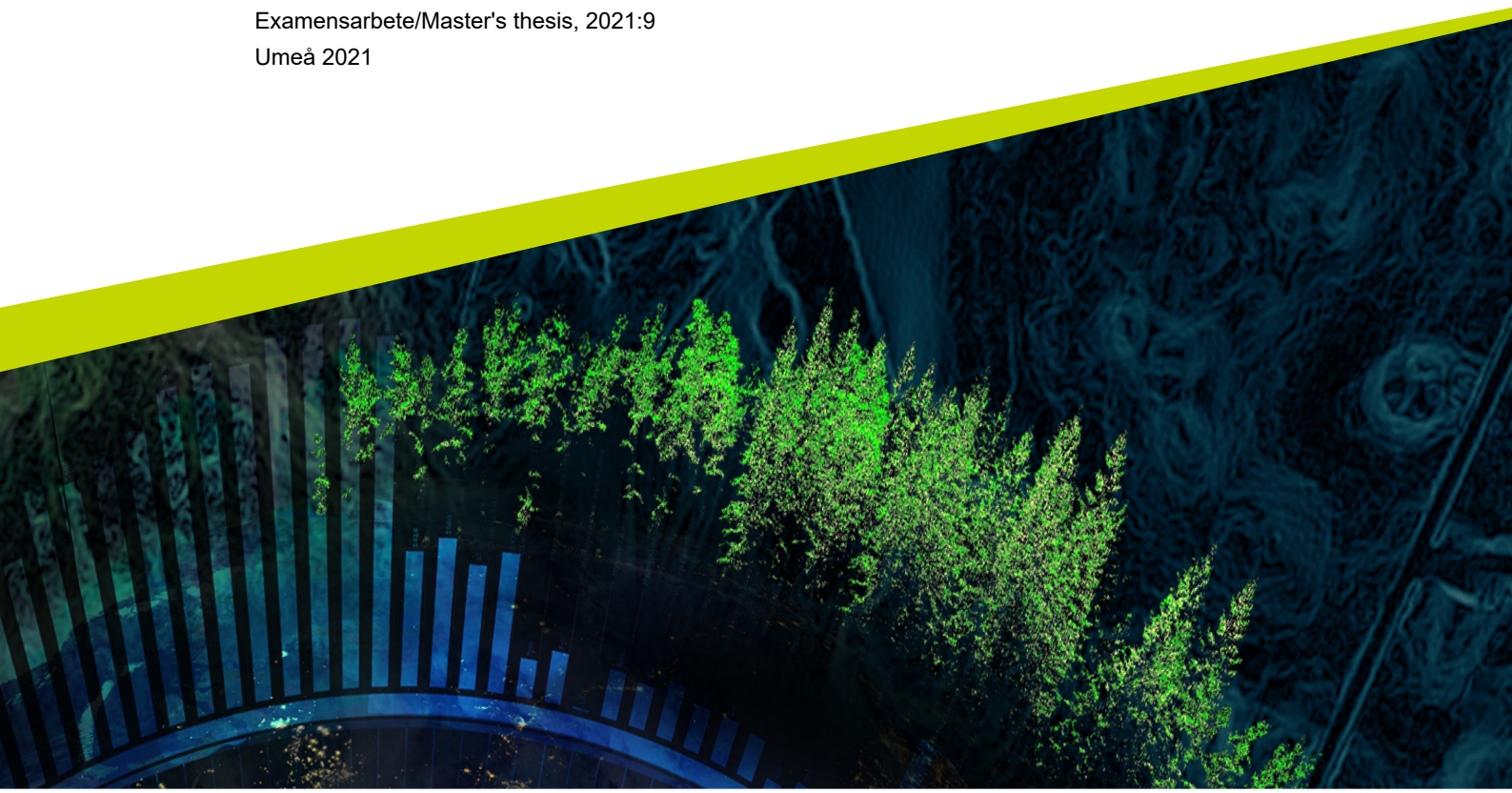

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Abstract

Ungulates foraging on and damaging agricultural crops are a common phenomenon worldwide, which create conflicts between stakeholders with different economic interests. Further, the spatiotemporal distribution of food and the quality of food is often referred to as the "foodscape". The purpose with this study was to gain knowledge about which factors determine the level of damage in crops created by foraging ungulates and investigate if drones can be used to estimate crop damage in a more efficient way. To estimate proportion biomass loss in both grass- and oat fields, I used exclosures that prevented ungulate foraging and compared the crop weight inside these exclosures with adjacent control plots that allowed foraging. Within each field, three exclosures were established, two near field edges and one in the center. Aiming to explain the variation in biomass loss, I used several different explanatory variables and conducted a linear mixed model with a backwards elimination approach, to determine the factors with the greatest impact. I also monitored all grass fields with a drone that captured multispectral images, which were used to create NDVI-maps over the fields. Further, I used the NDVI-maps and a linear mixed model to investigate if NDVI was correlated with biomass weight in grass fields. I found that proportion of arable land surrounding a field had the greatest impact on the variation in biomass loss. Proportion of arable land had a negative correlation with biomass loss for both oat- and grass fields. For grass fields, there were also a positive correlation between biomass weight in non-foraged plots and biomass loss. Furthermore, NDVI showed a strong positive correlation with biomass weight in grass fields, which suggests that drones could be used to streamline estimates of biomass loss in grass fields. In conclusion, the foodscape is an important factor determining agricultural damage by foraging ungulates. Therefore, instead of decreasing ungulate populations, more focus needs to be placed on improving the foodscape for ungulates.

Keywords: ungulates, foraging, biomass loss, NDVI, drones

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Introduction

Most of Europe's wild ungulate species have recovered from being severely declining during the late 19th and early 20th centuries due to human impact and are today widely spread in Europe (Linnell et al., 2020). At the same time, the human population is growing worldwide which demands higher food supplies (Bongaarts, 2009). This leads to a problem since a large part of ungulates daily food intake constitutes of crops from agricultural fields, which results in lower harvests and lower food production. For farmers, lower harvests generate lower income, while other stakeholders, such as hunters, benefit from high densities of ungulates when hunting, often leading to conflicts (Bleier et al., 2012; Côte et al., 2004; Linnell et al., 2020). In contrast, ungulates can also provide ecosystem services such as higher species diversity through effects on vegetation structure (Reimoser and Putman, 2010) and a high recreational and hunting value (Boman and Mattson, 2012; Menichetti et al., 2019). Ungulate distribution and forage behavior are mainly driven by perceived predation risk and the quality and availability of food, which both often depend on habitat structure (Laundré et al., 2001; Royo et al., 2017).

Regarding perceived predation risk, large predators, e.g., wolves (*Canis lupus*), pose a threat to wild ungulates (Laundré et al., 2001). This predation risk has both a direct effect (mortality) and an indirect effect (behavioral). The indirect behavioral effects in ungulates can lead to changes in movement and foraging patterns, where they often reduce time spent in high predation risk areas. In theory, this difference in predation risk in the landscape is often referred to as the "landscape of fear", and ungulates usually spend more time foraging where they have protection nearby rather than in open areas where they are more exposed to predation (Andrén et al., 2018; Bleier et al., 2012; Laundré et al., 2001). Similar behaviors have been shown in several studies for wild boar (*Sus scrofa*) (Bleier et al., 2012; Bleier et al., 2017; Thurfjell et al., 2009) and red deer (*Cervus elaphus*) (Bleier et al., 2012; Bleier et al., 2017; Trdan and Vidrih, 2008).

Further, if an area with high quality and availability of food also possesses an increased threat due to predators, ungulates face a trade-off between foraging and time spent on vigilance (Laundré et al., 2001; Mao et al., 2005). Regarding this trade-off, ungulates must consider if the disadvantage of increased threat from predators weighs up to the benefit of higher quality and availability of food. If not, ungulates will most likely move to other areas with lower predation risk. On the

other hand, in a landscape without predators or other threats, ungulates can choose to forage where it is most beneficial, which are in areas with high quality and availability of food (Laundré et al., 2001; Mao et al., 2005).

The spatiotemporal distribution of food and the quality of food is often referred to as the "foodscape" (Marsch et al., 2014; Wam and Herfindal, 2018). The foodscape can have great impact on herbivores foraging behaviors. For example, Marsch et al. (2014) showed that koalas (*Phascolarctos cinereus*), who is a mammalian browser, choose to feed in individual trees with high quality of food, while mainly using trees with lower quality for other activities, e.g., for resting.

Further, the foodscape has been found to influence the effect from foraging ungulates on vegetation (Royo et al., 2017). Royo et al. (2017) conducted a study where they found that the large-scale (259 ha) habitat structure and an increasing proportion of available food patches mitigated the negative effect on plant cover and species richness from foraging ungulates within a forest community.

The foodscape also has a large impact on carrying capacity for ungulates and therefore also on potential population densities (Côte et al., 2004). Previous studies found a positive correlation between agricultural damage and densities of e.g., wild boar and red deer (Bleier et al., 2012; Bleier et al., 2017). It is thus unclear what the long-term effects of increased quality and availability of food in the landscape will be and whether damage from ungulates will be mitigated or enhanced (Royo et al., 2017). Furthermore, in small-scale, patches with high availability of food have seen to attract more ungulates, leading to higher foraging intensity (Kuijper et al., 2009).

In Sweden, five large ungulates species with different food preferences are distributed in different parts of the country. Red deer and fallow deer (*Dama dama*) are mainly distributed in the middle of Sweden and southwards. Red deer is a native species, while fallow deer was introduced in 16th century and have during the last 10-20 years increased rapidly (Andrén, et al., 2018). They are both considered as intermediate feeders, i.e., they are opportunistic in their food selection and prefer a mixed diet (Andrén, et al., 2018; Bergvall, 2009; Hoffman, 1989; Spitzer et al., 2020). Moose (*Alces alces*) and roe deer (*Capreolus capreolus*) are more widely spread and found in most of Sweden, and wild boar are found from the southern parts of the province Norrland and southwards (Andrén, et al. 2018). Moose and roe deer are considered as selective browsers (Andrén, et al., 2018; Spitzer et al., 2020), while the hindgut-fermenting wild boar is an omnivore (Genow, 1981; Spitzer et al., 2020).

To be able to prevent/mitigate agricultural damage, we need more knowledge about which factors that are driving ungulates foraging behavior. This knowledge can then be incorporated in both agricultural and wildlife management plans, to prevent, or at least reduce further economic losses to different stakeholders. In Sweden, one recent study has tried to quantify yield losses in oat (*Avena sativa*) and winter wheat (*Triticum aestivum*) from fallow deer, while also looking at

interactions between landscape features and crop damage (Menichetti et al., 2019). Beyond that, no recent studies have been done in Sweden regarding which factors have the greatest impact on biomass loss by foraging ungulates in growing crops.

The aims of this study were to (1) quantify biomass loss from foraging ungulates, in both oat- and grass fields, (2) investigate which factors have the greatest impact on biomass loss in growing crops and (3) evaluate whether drones can be used to estimate biomass loss in grass fields.

I predicted that (1) there will be a high variation in biomass loss between different locations. Further, I predicted that (2) ungulate density will have a large impact on biomass loss in both crop types and that (3) drones could be an important tool when estimating biomass loss in grass fields.

1. Materials and method

1.1. Study area

Figure 1: *A map showing the study area. Red dots are representing grass fields and black dots oat fields.*

The study area is situated between Nyköping and Gnesta, in the eastern part of the county Södermanland (Sweden) (fig. 1). The study site covers a large area with mixed landscape, and with high abundances of ungulates. For the study area, I calculated estimated deer densities for the winter in 2018-2019, using pellet count data (Beyond Moose, unpublished data) and previously used methodology (Pfeffer et al., 2017), defecation rates and accumulation time (FOMA, 2015). Among deer species, the most common are fallow deer with 105-127 individuals/10 km^2, followed by roe deer with 40-52 individuals/10 km^2, red deer with 8-12 individuals/10 km^2 and moose with 3-5 individuals/10 km^2.

I chose to only incorporate fallow deer in the analyses because of following reasons. Despite the high roe deer density, previous studies have not seen any significant correlation between roe deer density and crop damage (Bleier et al., 2012) and moose diet does not include a large amount of crops (Spitzer et al., 2020). I did not include wild boar either due to low pellet densities compared to fallow deer for the study area. Further, I did not include red deer since their diet has been seen to include a lower proportion of grasses (38 %) than fallow deer (56%) during growing season (Spitzer et al., 2020), and for the study area there were a significantly higher density of fallow deer than red deer.

1.2. Experimental setup

With permission from the landowners, a total of 48 fields were selected for the study, where 32 of them were grass fields and the other 16 were oat fields. By using both grass- and oat fields, comparison in biomass loss could be made in between them, where grass in general are found to be a less attractive food for ungulates than oat. The grass fields were seeded in different years, while all oat fields were seeded during spring in 2020. The fields were evenly distributed by location and ranged from 1 to 13 hectares in size (fig. 1).

In each field, I established three exclosures where ungulate foraging was prevented. Exclosures were 2.24 x 2.24m (fig. 2), with a height of 1.63m and made of timber piles and rebar with a mesh size of 14 x 14cm (fig. 3) which excluded mammals larger than european hare (*Lepus europaeus*). I divided the area inside each exclosure into one centered square meter (test plot) and a buffer zone covering the rest of the area (fig. 2). The purpose of the buffer zone was to create similar conditions for the test plot, that it would have been without grazing in the absolute near surrounding. Without a buffer zone, and less vegetation in the absolute near surrounding due to intensive grazing, the growth conditions for the grass/oat in the test plot would most likely be more favorable because of lower competition (Freckleton et al., 2009).

To test if distance to cover influenced foraging intensity, I placed one exclosure in the center of the field (point with longest distance to any edge) and two on edge in a stratified random way with the help of GIS and a handheld GPS (Garmin MAP 64s). Exclosures near field edges were placed 10 meters inside the edge (fig. 2), and were divided into two different categories, depending on the type of field edge: Forest (forest/protection nearby) and No Forest (no forest/protection nearby). I put out the exclosures on grass fields in April and on oat fields directly after they were seeded in April/May.

I paired the exclosures with adjacent control plots, which simulated normal conditions with ungulate foraging. Control plots were one square meter and the

placement where five meters south of the exclosure in the center and five meters to the right, parallel to the field border while facing it, for exclosures near field edges (fig. 2 and 4).

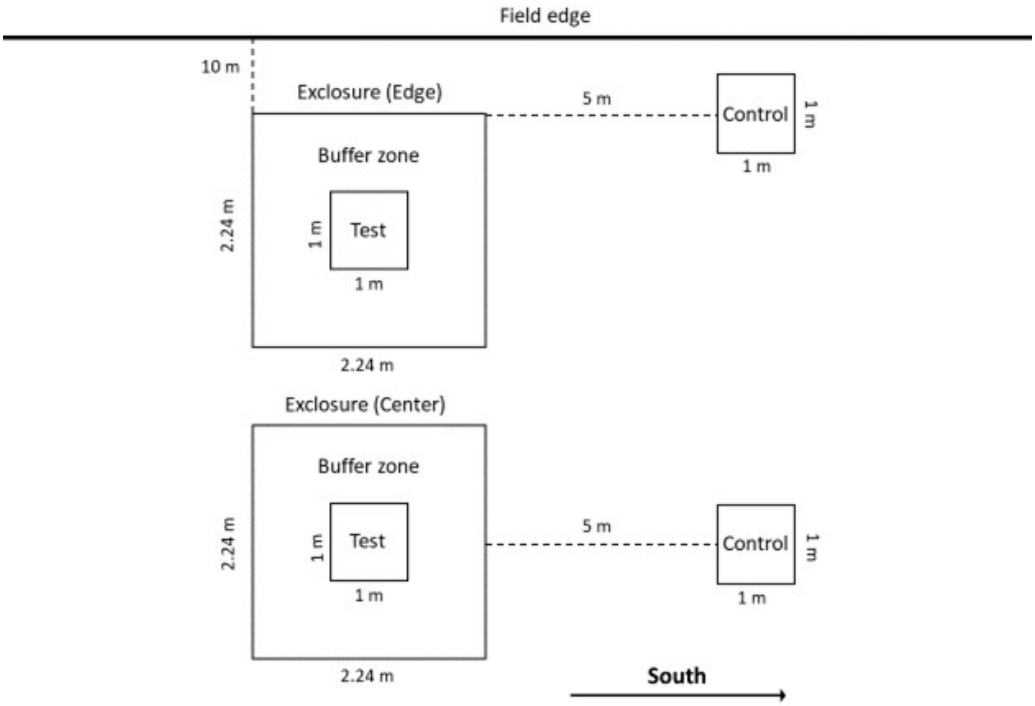

Figure 2: *A sketch illustrating the experimental setup. Exclosures placed in a stratified random way, with a centered test plot and a buffer zone. Adjacent control plots, corresponding to the test plots, were located 5 m from the exclosures as illustrated.*

Figure 3: *Image of an exclosure on a grass field before first measurement. The exclosure is constructed of two timber piles and four 2.24 m sides made of rebar. ©Ingemar Parck*

Figure 4: *Drone image showing the experimental setup for an exclosure placed in the center of the field. To the left, the exclosure with the test plot in the center. To the right, the control plot placed 5 m south of the exclosure as displayed in fig. 2. ©Ingemar Parck*

1.3. Data collection and analyses

1.3.1. Exclosure measurements

I collected data two times for the majority of the grass fields, one in May/June and one in July/August in conjunction with harvest. I excluded data from the second measurement for some fields, where the first harvest was postponed into late July and no representative data could be collected. The exclosures had been up for an average of 45 days when the measurements were conducted. In each exclosure, I manually (using electric scissors) cut the grass in both the test plot and the buffer zone, weighted it separately on a digital scale, and took notes on the wet weight in gram and the exclosure placement. I cut the grass approximately 5 cm above the soil, depending on the smoothness of the surface, to simulate a normal harvest. I cut and collected the grass in the same way in the adjacent control plots, corresponding to the test plot in the center of the exclosure (fig. 2 and 4). After the first measurement period, I removed the exclosures so the farmers could harvest the fields. When the harvest was conducted, I put back the exclosures on the fields to get a new starting point for the second measurement.

I collected data for each oat field once in August, when it was mature and ready for harvest. The exclosures had then been up for an average of 94 days. I cut the oat

in the same way as the grass, and I weighted the whole straw with grains, both inside the exclosures and in the control plots.

For both oat and grass, I quantified biomass loss by taking the weight difference between the test (no foraging) and control (foraging) plot and divided the difference with the weight in the test plot.

$$\frac{(Test\ plot - Control\ plot)}{Test\ plot} = Proportion\ biomass\ loss$$

Negative values generated from the formula means that a higher biomass weight was collected in the control plot than in the test plot. Therefore, I assumed that there was no effect from foraging for these exclosures and the negative values were set to zero.

1.3.2. Pellet count data

I used pre-collected pellet count data from spring 2019, as a measure of the winter population in 2018-2019 (Beyond Moose, unpublished data). Each field were approximately centered inside a hollow grid of 4km (1 x 1km). Each transect had a total of 16 sample areas with 200 m separation, where each sample area was 10m^2 (In reference: 100m^2) (Pfeffer et al., 2017) (fig. 5). A fallow deer pellet density index per 100m^2 was already calculated for each field, with following formula:

$$\frac{(Total\ number\ of\ counted\ pellet\ piles\ x\ 10)}{Number\ of\ sample\ areas}$$

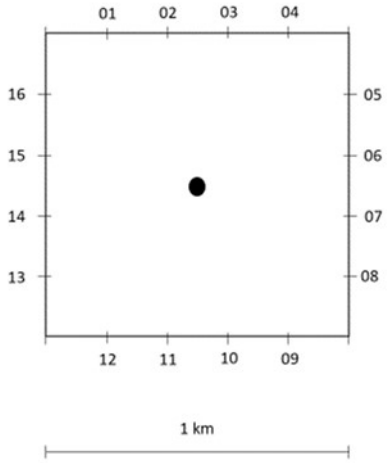

Figure 5: *A sketch illustrating a square transect of 4km, with 1 x 1 km sides and 16 sample areas. The fields were approximately centered inside the tracts.*

I used this pellet density index as an estimation of fallow deer density around each field. I used pellet density index instead of absolute fallow deer density since it has proved to be a good indicator and the conversion from pellet density to absolute density have shown to lack accuracy, because of low knowledge about the defecation rate (Bergström et al., 2011; Plhal et al., 2014).

To take in consideration is that I used the newest available pellet count data for the moment, which was a measure of the winter population of fallow deer in 2018-

2019. Therefore, I assumed that the fallow deer population had not changed significantly between 2019-2020, and that the data were still representative.

1.3.3. Surrounding habitats

I used the national ground cover data from Swedish Environmental Protections Agency and QGIS 3.12 to quantify the different habitats in a 500m buffer surrounding each field. I divided the different habitats into 6 categories: forest (all types and ages of forest, including clear-cuts), arable land, other open areas (e.g., pastures), water, wetlands, and exploited area (e.g., roads, buildings). I choose a 500m buffer for two main reasons: the average area quantified around each field with a 500m buffer is approximately 130 ha, which corresponds quite well with the home range for a fallow deer during the summer months (Andrén et al., 2018). Secondly, from the fields there are approximately 500m to the sides of the tracts where the fallow deer pellets were sampled, which allows the quantifying of surrounding habitats to be compared with pellet density index for fallow deer.

1.3.4. Drone monitoring

NDVI

The Normalized Difference Vegetation Index (NDVI) is an indicator of the growth and development on plants (Rouse et al., 1974). Previous studies have shown a strong relationship between NDVI and vegetation productivity, therefore it can be used to monitor crops condition. NDVI is derived from multispectral sensors that captures the light reflected from both the visible and near infrared light (Mogili and Deepak, 2018; Pettorelli et al., 2005). In recent years, unmanned aerial vehicle (drones) have gained tremendous importance for vegetation-monitoring purposes, as they can carry different types of sensors (including multispectral cameras) to capture field images carrying crop information (Mogili and Deepak, 2018).

Calculating NDVI, a value between -1 – +1 can be generated with a formula (formula 1) including the red and near infrared reflection ratio:

$$\frac{(Near\ infrared - Red)}{(Near\ infrared + Red)} = NDVI$$

Values below zero (negative values) denote an absence of vegetation, while values above zero (positive values) indicates vegetation, with values close to 1 indicating a high level of vegetative biomass (Mogili and Deepak, 2018; Pettorelli et al., 2005).

Drone

I monitored the grass fields with a drone right before each exclosure measurement was conducted. The drone I used was a DJI Phantom 4 Multispectral, which has the capacity to capture multispectral images. The DJI Phantom 4 Multispectral has six different cameras and captures images in five different wavelengths: blue (450 ± 16 nm), green (560 ± 16 nm), red (650 ± 16 nm), red edge (730 ± 16 nm) and near infrared (840 ± 26 nm). Additionally, the sixth camera acquires traditional RGB images.

I made flight routes in the application DJI GS Pro for accurate flights. There are regulations for flight altitude and for some sites in the study area, 50 m was the highest legal altitude (Swedish Transport Agency, 2021). Therefore, I conducted all flights on 50 m altitude to get comparable results between the fields. During the flight route, images were captured with an 80 % front overlap and a 60 % side overlap. I choose these settings as a trade-off between time efficiency and resolution, which was approximately 2,6 cm/pixel for these settings. I used the Pix4D-mapper software (version 4.5.6) (Pix4d.com, 2021) to process the multispectral images. First radiometric correction was done using images of a calibration target (Airinov) acquired before and after each flight (Duan et al., 2017); second, image orthomosaics was generated and finally NDVI-maps was created (formula 1).

I then imported the NDVI-maps (Processed in Pix4Dmapper by Pix4d) to QGIS 3.12 and used the software to analyze the correlation between NDVI and biomass for grass fields. To do that, I extracted the mean NDVI-value from inside the exclosures using QGIS (fig. 6). I then used the actual measured weight inside the same exclosures, converted the weight to g/m^2, and paired the value with the NDVI-value. To get additional samples for the correlation between NDVI and biomass, I put out a sample plot (1 m^2) 5 m north of the center exclosure and flew it with the same settings before I cut and weighted the grass with the same method as for the exclosures.

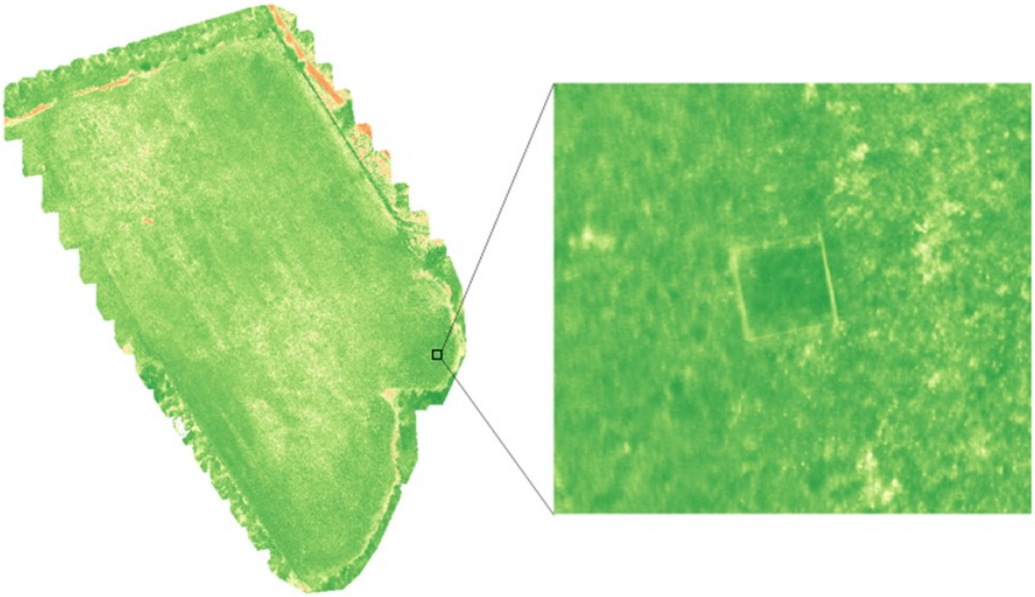

Figure 6: *NDVI-map over a grass field in connection with the first measurement. To the right, a zoomed in image of an edge exclosure, where a mean NDVI-value was extracted from inside the exclosure (quadrant with bright sides). In the image, the color palette for NDVI ranges from red (low NDVI) to green (higher NDVI).*

1.4. Statistical analyses

All the statistical analyses were done in SPSS version 26, and the graphs were made in Excel 2016. In all analyses, p-values less than 0.05 were considered statistically significant.

1.4.1. Factors determining biomass loss from foraging ungulates

I used linear mixed models (LMM) to test which factors had the greatest impact on biomass loss in growing crops from ungulate foraging. I used a backwards elimination approach, where I removed explanatory variables with p-values exceeding 0.1, one at a time, until I only had variables with p-values less than 0.1. I performed two separate tests, one for grass fields and one for oat fields.

I made a correlation matrix (for oat- and grass fields separately) that included proportion biomass loss and the proportions of the different surrounding habitat categories, to evaluate which habitat type to include in the model. For both crop types, only proportion forest and proportion arable land showed a correlation with biomass loss. Since they were the two dominant habitat types, they were strongly correlated with each other and could not both be included in the model. Therefore, I choose to use proportion arable land in both tests, to facilitate the interpretation of the results.

Grass

As target variable, I used proportion biomass loss, where negative values had been set to zero. I used proportion arable land, biomass in test plot, exclosure placement and pellet density index for fallow deer as explanatory variables. In addition to the explanatory variables explained earlier in the method, I used biomass in test plot to check if difference in availability of food (small-scale) in crops influenced biomass loss from foraging ungulates. Except from exclosure placement (categorical), I scaled all explanatory variables for comparison, by subtracting the mean and dividing by one standard deviation.

To correct for differences in number of days the exclosures had been up before measurements and for differences in growth conditions between fields, I used fields as a random factor. I also set my data structure to correct for repeated measurements, since most of the exclosures were measured twice, once in May/June and once in July/August.

Oat

I set the target variable the same way as for grass. I used proportion arable land, biomass in test plot, exclosure placement and pellet density index for fallow deer as explanatory variables. I included biomass in test plot for the same reason as in the test for grass, to check if difference in availability of food (small-scale) in crops influenced biomass loss from foraging ungulates.

To correct for differences in number of days the exclosures had been up before measurements and for differences in growth conditions between fields, I used fields as a random factor.

1.4.2. Correlation between NDVI and biomass in grass fields

I used a linear mixed model (LMM) to test the correlation between NDVI-values and biomass in grass fields.

To achieve linear data, I log-transformed the target variable, weight in g/m^2 (derived from the measurements) before I used it in the model. I used the corresponding mean NDVI-value, extracted from the drone images, as explanatory variable. I used fields as a random factor to correct for differences between fields and I also set my data structure to correct for repeated measurements, since I collected the data from two different measurements periods, April/May and July/August.

2. Results

2.1. Quantifying biomass loss in oat- and grass fields

Figure 7: *Images showing the high variation in biomass loss between grass fields. To the left, exclosure on a field with low foraging intensity and low biomass loss. To the right on the other hand, an exclosure on a field with very high foraging intensity, where (more or less) all grass outside the exclosure is foraged.*

Figure 8: *Images showing the high variation in biomass loss between oat fields. To the left, exclosure on a field with very low foraging intensity and with almost no biomass loss. To the right on the other hand, an exclosure on a field with very high foraging intensity, where (more or less) all oat outside the exclosure is foraged.*

The estimated biomass loss (values reported in mean ± SD) between the test and adjacent control plot were for grass 34.1 ± 28.8 % (fig. 7) and for oat 64.4 ± 35.7 % (fig. 8). For grass, 36 out of 168 exclosure measurements showed no biomass loss at all from foraging ungulates, while corresponding number for oat were 5 out of 46.

2.2. Factors determining biomass loss from foraging ungulates

2.2.1. Grass

The final model for grass included biomass in the test plot and the proportion of arable land surrounding the field. The difference in biomass between test and control plots decreased with increasing proportion of arable land (coefficient = -0.061, p = 0.034, 95% CI = -0.117 - -0.005) (fig. 9). Further, the difference in biomass increased with the biomass in the test plot (coefficient = 0.056, p = 0.015, 95% CI = 0.011 - 0.101) (fig. 10).

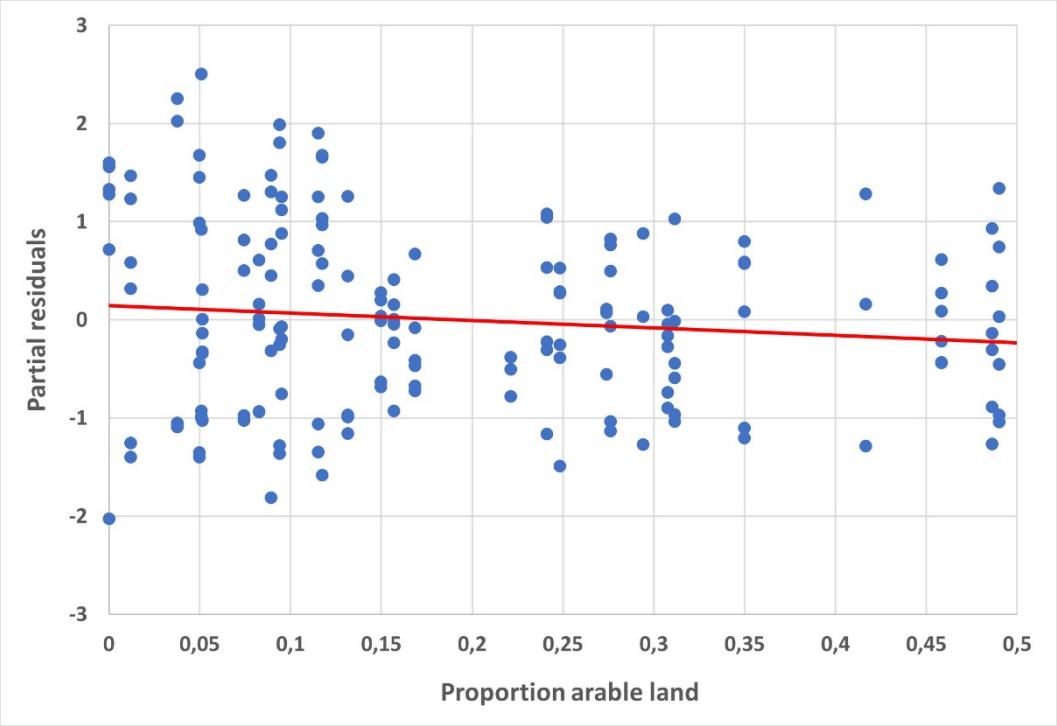

Figure 9: *Partial residual plot with residuals derived from the LMM, where proportion arable land was excluded. The trendline (in red) shows the predicted relationship.*

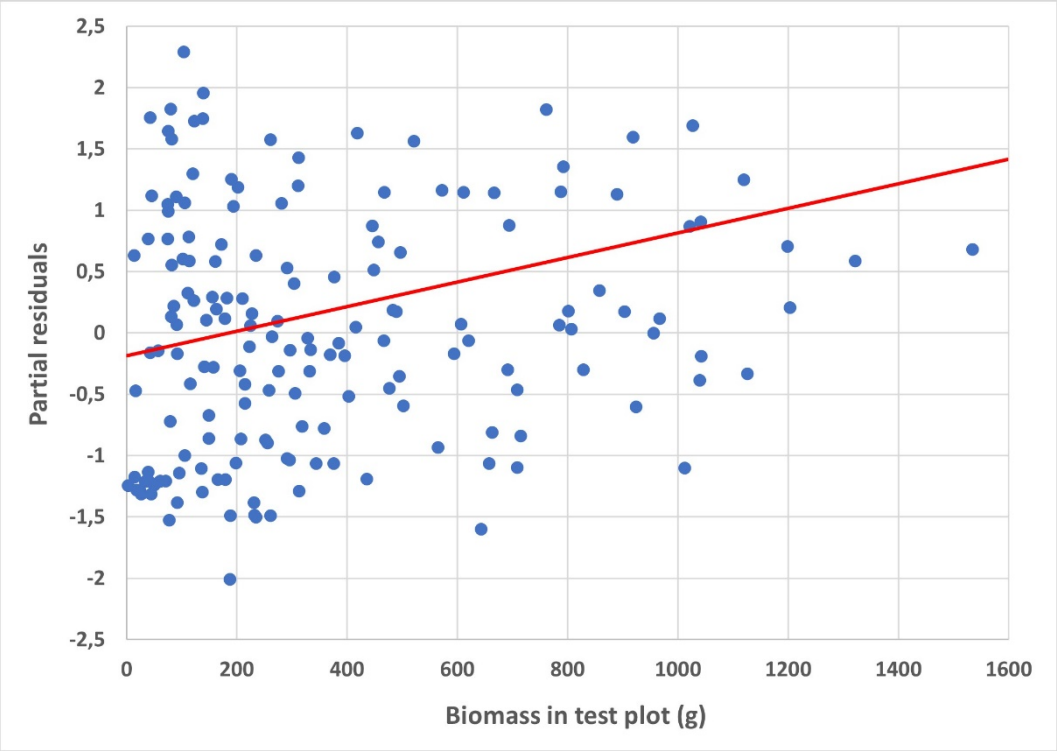

Figure 10: *Partial residual plot with residuals derived from the LMM, where biomass in test plot was excluded. The trendline (in red) shows the predicted relationship.*

2.2.2. Oat

The final model for oat included the proportion of arable land surrounding the field. The difference in biomass between test and control plots decreased with increasing proportion of arable land (coefficient = -1.465, $p < 0.001$, 95% CI = -2.009 - -0.922) (fig. 11).

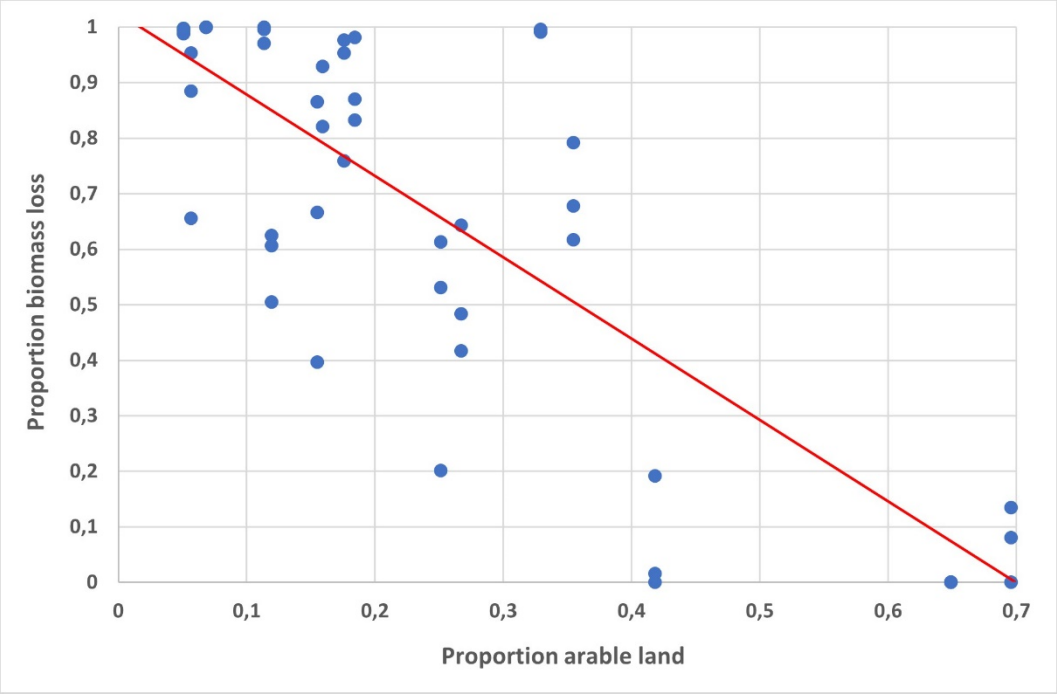

Figure 11: *Scatter plot showing the correlation between proportion arable and proportion biomass loss in oat fields. The trendline (in red) shows the predicted relationship.*

2.3. Correlation between NDVI and biomass in grass fields

The model showed a strong correlation between NDVI and log-transformed biomass in grass fields. Biomass for grass increased with NDVI (coefficient = 2.593, $p < 0.001$, 95% CI = 2.170-3.016) (fig. 12). A scatter plot with non-transformed data shows that the curve saturates at NDVI-values around 0.85 (fig. 13).

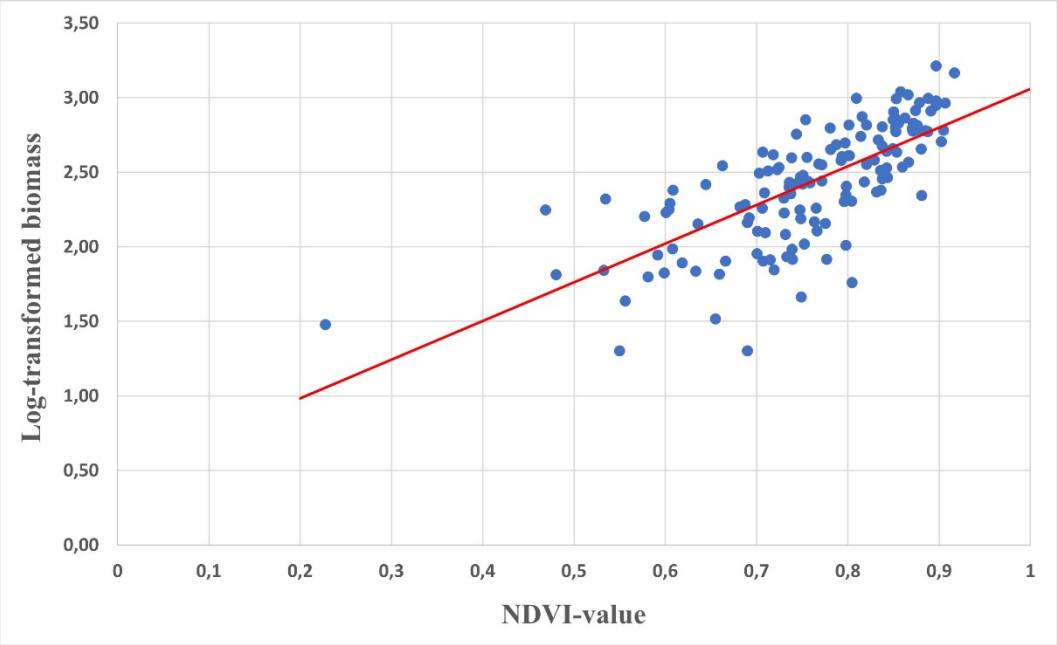

Figure 12: *Scatter plot showing the correlation between NDVI and log-transformed biomass values. The trendline (in red) shows the predicted relationship.*

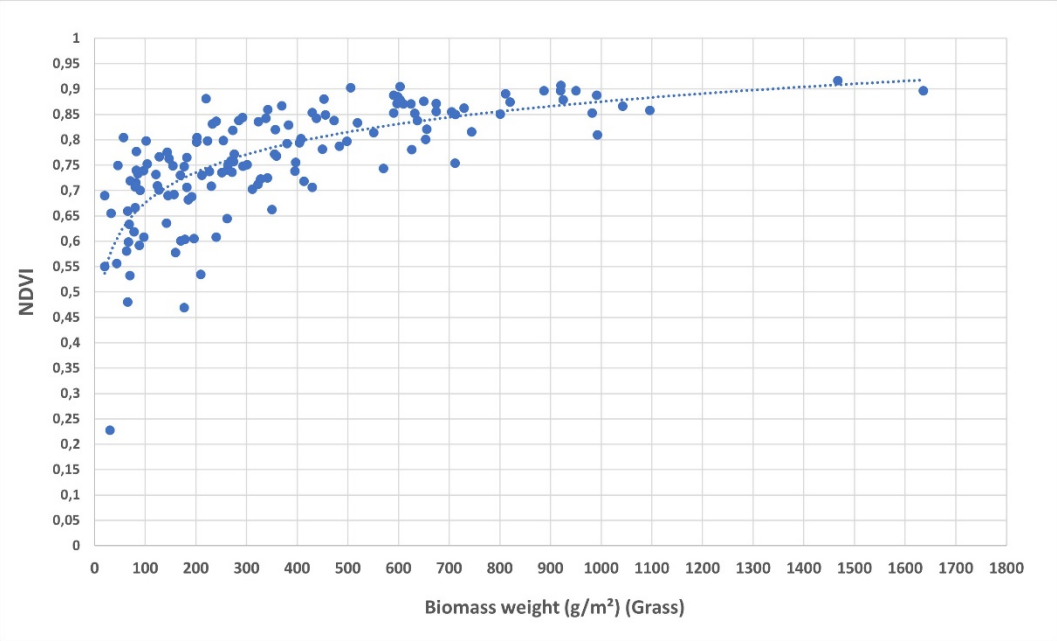

Figure 13: *Scatter plot showing, with non-transformed data, the correlation between NDVI and weight (g/m^2) in grass. The curve saturates at NDVI-values around 0,85. R^2-value = 0,5343.*

3. Discussion

My analyses of factors determining agricultural damage caused by foraging ungulates showed that proportion of arable land surrounding a field had the greatest impact on biomass loss for both crop types. I also found a weaker significant positive correlation between biomass loss and biomass in test plot for grass fields. This indicates that the foodscape rather than ungulate densities might be the most important factor determining agricultural damage. Further, I also found a strong correlation between NDVI and biomass in grass fields, which suggests that drones can be used to measure biomass at large surfaces and to streamline the estimates of biomass loss in grass fields.

3.1. Quantifying biomass loss in oat- and grass fields

I found a large variation in biomass loss between fields (fig. 7 and 8). Since I had no cameras capturing images on the control plots during the time of the exclosure experiment, I cannot exclude that other animals than ungulates where foraging and causing biomass loss in the fields. However, when conducting the measurements, I often both visually saw ungulates and found pellets from them on the fields. Further, with the used mesh size of 14 x 14cm, all herbivores smaller than ungulates should be able to forage both outside and inside the exclosures which should correct for biomass loss caused by other foraging herbivores. An exception would be larger birds (e.g., geese or swans) that could forage outside but not inside the exclosures, due to problem with either walking in to the exclosure or landing inside of it. However, I in general found very few tracks from larger birds that potentially could have been foraging on the fields and I therefore assume that the measured biomass loss was represented by foraging ungulates.

Looking at grass fields, 36 out of 168 measured exclosures did not show any biomass loss at all from foraging ungulates. Where foraging was present, the estimated difference in biomass, between test- and control plot, was on average 34.1 %. These results can be compared with a previous study from southeastern Slovenia, where they looked at the effect from red deer grazing on grasslands. They showed a mean yield decrease in herbage (dry matter) between 38 and 68 % in three

different areas, as a result from red deer grazing (Trdan and Vidrih, 2008). In other words, one area in their study (38 %) was relatively well in line with what I found, while other areas showed a much higher biomass loss.

For oat, the estimated biomass loss in the control plot was on average 64.4 %, where 5 out of 46 exclosures did not show any effect from foraging. Menichetti et al. (2019) conducted a similar study on a large estate in south-west of Sweden, where they prevented fallow deer from grazing in areas enclosed by cages and compared the amount of biomass (dry weight) in the area with control plots that allowed grazing. Their results showed an average of 18.9 % in total oat (whole straw with grain) biomass loss, which is much lower than the results from this study.

There could be several reasons for the difference in average biomass loss between this study and the studies conducted by Trdan and Vidrih (2008) and Menichetti et al. (2019). However, the surrounding foodscape could be explaining a large part of the difference in average biomass loss that was found between our studies.

I found that oat fields showed the largest difference in average biomass loss compared with previous studies. In my study, oat fields showed a large variation in biomass loss, spanning from 0 – 100 %, which was strongly correlated with proportion of arable land surrounding a field (fig. 11). However, the majority of the oat fields in my study had a low proportion of surrounding arable land, which led to a high average in biomass loss (fig. 11). Further, Menichetti et al. (2019) established all sample plots on oat fields that where close to, both each other, and to other wheat fields, which potentially could have resulted in a lower average in biomass loss. In other words, differences in the foodscape, both within my study area, and between mine and the area used by Menichetti et al. (2019), probably led to a significantly higher average in biomass loss in my study.

Further, the higher average in biomass loss in grass fields that was found by Trdan and Vidrih (2008), can probably also be explained by the foodscape. Trdan and Vidrih (2008) conducted their study in an area with a high proportion of woodland (low proportion arable land), which considering my results should lead to higher biomass loss.

Furthermore, in contrary to the compared studies, I used the wet weight when calculating proportion biomass loss, which also could have led to potential differences in average biomass loss between our studies. By using wet weight, I might get a larger variation in measured biomass weights compared to if I would have used dry weights instead. Unfortunately, due to time constraints, I did not have the possibility to use dry weights which potentially could have been a better alternative, even if I believe that my measured biomass weights were reliable.

When I compare the average in biomass loss between the crop types in my study, I found almost twice as high average biomass loss in oat fields (64.4 %) than in grass fields (34.1 %). Some part of this difference in average biomass loss could

probably be explained by the difference in regrowth between oat and grass, where e.g., grass have shown to compensate loss of biomass by an increased relative growth rate (Ferraro and Oesterheld, 2002). Further, if oat fields, compared to grass fields, contains higher quality of food, ungulates will probably choose to forage in oat fields which most likely leads to higher foraging intensity and biomass loss (Alm et al., 2002).

To investigate whether that is the case for this study, it would be interesting with research on whether oat has a higher quality as food for ungulates than grass, and how that knowledge could be incorporated in management implications.

3.2. Factors determining biomass loss in oat- and grass fields from foraging ungulates

I predicted that ungulate density would play a major role in explaining biomass loss in crops, since previous studies found a positive correlation between agricultural damage and densities of e.g., wild boar and red deer (Bleier et al., 2012; Bleier et al., 2017).

However, fallow deer pellet density index was not included in the final model for neither grass- nor oat fields. In other words, even if ungulate density most likely influences biomass loss, there are other factors that play a more important role in determining biomass loss, which has been seen in both agricultural (Lombardini et al., 2017) and forest systems (Jarnemo et al., 2014; Kuijper, 2011; Pfeffer et al., 2021).

The placement of exclosures did not have any significant effect for either of the two crop types. I anticipated that there would be higher foraging intensity and higher biomass loss near field edges where forest/protection was nearby, something that has been shown by several earlier studies for e.g., wild boar and red deer (Bleier et al., 2017; Thurfjell et al., 2009; Trdan and Vidrih, 2008). However, Menichetti et al. (2019), who also conducted their study in a landscape dominated by fallow deer, found a similar result. They could not find any influence on foraging intensity in oat from either distance to forest, houses, roads, or other anthropogenic features. Instead, Menichetti et al. (2019) found that visibility from roads explained a large part of foraging intensity in oat, why they suggested that fallow deer has the potential to make a risk evaluation and that they experience being visible to humans as the greatest risk.

Weight/amount of biomass in test plots was used to check if difference in availability of food (small-scale) influenced foraging intensity, were I anticipated that higher availability of food would attract more ungulates and increase foraging intensity (Kuijper et al., 2009). For oat, I did not find any such correlation, while

for grass fields, biomass loss had a significant positive correlation with the weight/amount of biomass in test plots (fig. 10). The correlation I found for grass is in line with a previous study, where Kuijper et al. (2009) found that ungulates preferred to browse in areas with high availability of food (forest gaps), rather than in areas with lower availability of food (closed forests).

In this study, I found that the factor having the greatest impact on biomass loss, in both grass- and oat fields, were the habitats surrounding a field in a landscape scale. I found that proportion of arable land surrounding a field was negatively correlated with biomass loss for both crop types, where it explained the variance in biomass loss for oat greater than for grass (fig. 9 and 11).

The question is, what is the most important influence from increasing proportion arable land on crop damage, the decreasing access to protection or the increasing quality and availability of food?

For this study, neither exclosure placement nor fallow deer pellet density seemed to have any significant correlation with biomass loss, which suggests that the foodscape plays the major role here. If fallow deer showed a strong avoidance behavior and protection would be the strongest driver, I assume that there also would be a higher difference in forage intensity within fields, which was not found for the different exclosure placements. Further, I also assume that if protection were the main driver, and fallow deer avoided arable land frequently due to lower protection, there would most likely be fewer fallow deer pellets in these areas which would boost the effect from fallow deer pellet density in the statistical tests.

In a recent study, Pfeffer et al. (2021) showed that Scots pine (*Pinus sylvestris*) density is one of the most important predictors of browsing damage in Sweden. Further, Pfeffer et al. (2021) showed that browsing damage decreased with increasing pine density, which is the same pattern I found for arable land in this study. With increasing proportion arable land, which is improving the foodscape for ungulates, each field gets less prone to damage from foraging ungulates.

Other studies also showed, in a forest landscape, that an improved foodscape for ungulates could ease the overall foraging intensity (Jarnemo et al. 2014; Royo et al., 2017). Therefore, my conclusion is that the surrounding foodscape is the most important factor determining agricultural damage from foraging ungulates in this study area.

3.3. Drones – a potential future tool for estimating biomass loss in grass fields

Drones, carrying a multispectral camera, have proved before to be a time efficient way to monitor crops in field scale, and correlations have been found e.g., between NDVI and wheat yield (Duan et al., 2017). In this study, I found that biomass in grass fields correlate strongly with NDVI. However, the curve saturates at NDVI-values around 0.85 (fig. 13), which could be problematic in fields with very high biomass density.

In addition to using vegetation indexes, there are other methods that can be used to estimate biomass like e.g., plant height information. For example, Bendig et al. (2015) showed that plant height, derived from a crop surface model, was a strong parameter when estimating biomass in summer barley (*Hordeum vulgare*). Therefore, using plant height as a parameter, both alone or combined with vegetation indexes, when estimating biomass in grass- or oat fields should be considered as an alternative.

However, even if the conversion from NDVI to weight in biomass is not perfect, it could be accurate enough to be used practically. I also see improvements that potentially could enhance the precision in the capturing of NDVI. Lower flight altitude and a higher overlap in images are two aspects that probably would have generated higher resolution and more accurate results. It would be interesting to e.g., increase the side overlap in images from 60 to 80 % and investigate whether it results in more accurate NDVI-values, and whether that improvement is significant or not. Unfortunately, due to time constraints, I did not test this in my study.

Even if the possibility to estimate actual biomass in grass fields could be valuable alone, an even larger area of use would arise if drones also could be used to estimate biomass/yield loss in grass fields. However, to be able to estimate biomass/yield loss in grass fields with drones alone, it would be necessary to know how much biomass there would be without ungulates foraging. The problem is that there are several different factors that determine potential growth and biomass in grass fields (Harrison and Bardgett, 2010).

However, if drones could be used to estimate biomass in grass fields, it would be possible to scale up the methodology I used in this study, since less time would be needed to measure biomass inside and outside exclosures. Further, farmers could place a reasonable number of exclosures on fields exposed to damage and reliable measurements on biomass/yield losses could then be gathered in a more efficient way with drones. These data could then serve as material for governments, and perhaps be used to economically compensate farmers for yield losses.

In Sweden today, there are methods to estimate browsing damage in forest systems on a national scale, but there are yet no efficient way to estimate

biomass/yield loss in agricultural lands. However, drones could play an important role in filling this gap and making it possible to estimate biomass/yield loss on a national scale.

Further research needs to be done regarding this subject. However, this study shows that there is potential in the future to implement drones in a larger scale, as a tool to streamline estimation of biomass/yield losses.

3.4. Management implications

When interpreting the results from this study, it appears that the problem does not only lie in wildlife management, but landscape management seem to be least as important. Instead of preventing crop damage by reducing ungulate densities, it might be more effective trying to increase the quality and availability of food in the landscape, to steer away foraging pressure from agricultural fields to areas where it is not as costly for farmers.

One way to achieve this could be through dissuasive spreading of food in areas surrounding agricultural fields. For example, Calenge et al. (2004) examined the effect of spreading maize in areas surrounding Mediterranean vineyards where damage from wild boar were a reoccurring problem, and they found that by increasing the availability of food, both the proportion of damaged vineyards and the level of damage in vineyards were reduced.

Another way of improving the landscape of food for ungulates could be by creating food plots. Månsson et al. (2015) conducted an experimental study in Sweden, where they created food plots by seeding fields with different types of crops. At a landscape scale, they found a decreasing browsing pressure on valuable young Scots pine stands, which was a result from an improved foodscape generated by the food plots. Further, they also found an increased browsing pressure in the vicinity of food plots, why food plots preferably should be located with some distance to the area where high forage intensity wants to be prevented (Månsson et al., 2015).

In addition to improving the foodscape for ungulates, creating a landscape of fear through hunting could make the diversion of ungulates to acceptable areas even more effective. To create a landscape of fear through hunting, a high hunting pressure should be applied on the agricultural fields where foraging by ungulates wants to be reduced, while at the same time creating a free zone with no hunting in areas where e.g., food plots have been established. This hunting strategy would create areas with high perceived hunting risk (agricultural fields) where ungulates would reduce their time spent on foraging due to fear responses and areas with low perceived hunting risk (e.g., established food plots) where ungulates instead would spend more time foraging (Cromsigt et al., 2013). Further, if an improved foodscape

would increase the density of ungulates, hunting could be used to keep the ungulate populations at a stable level.

In conclusion, more research is needed about how to improve the foodscape, to divert ungulates away from the economically valuable agricultural fields. However, if we can provide ungulates with attractive food patches where high foraging intensities can be accepted, we could both enjoy the benefits of having sustainable ungulate populations, whilst minimizing agricultural damage.

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